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Educational robotics and primary school mathematics teaching: An analysis of pre-service teachers didactic-mathematical knowledge

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Abstract

The scarcity of studies dedicated to the integration of educational robotics (ER) in teaching mathematical content, and the discomfort of teachers when integrating ER in their teaching practices make it pertinent to understand the development of the didactic knowledge of mathematics necessary to integrate ER in mathematics teaching practices during initial teacher training. This qualitative and interpretive study identifies the knowledge of the didactic dimension from the didactic-mathematical knowledge conceptual framework that is mobilized by pre-service teachers (PST) during the implementation of mathematical tasks that integrate ER during the practicum. Through content analysis of the data collected on the PST's performance, we mapped the occurrence and co-occurrence based on the components of the didactic suitability criteria. From the results, we highlight: (i) the existence of a relationship between the mathematical knowledge needed to teach, knowledge of the mathematics curriculum, and knowledge of ER and how its integration in the teaching process can influence the learning process and (ii) the positive contribution of the implementation in the practicum of mathematical tasks that promote robot manipulation/programming at the same time as the exploration of the mathematical content for the development of the participants' didactic knowledge of mathematics. A practical implication of our results is that these features should be part of future work dedicated to integrating ER in mathematics teaching practices of PST, aiming to assess their value in initial teacher training programs.

Keywords: mathematics education, educational robotics, initial teacher training, practicum, didactic suitability criteria

INTRODUCTION

The integration of technology in teaching practices has been gaining prominence in the scientific community (Lai et al., 2023) and importance in the recommendations of international institutions (European Commission, 2020, 2022; OECD, 2019, 2022). Although technology's role in creating favorable conditions for meaningful learning is recognized (Akram et al., 2022), the integration of technology in teaching practices is conditioned by contextual barriers, as well as teachers' attitudes, beliefs (Lai et al., 2023), and knowledge (Taimalu & Luik, 2019), influencing what can be taught and how it is taught (Drijvers, 2015; NCTM, 2014). Participation in initiatives dedicated to professional development contributes positively to teachers being able to overcome these barriers and properly integrate technology in teaching and learning processes (Gomez et al., 2022). In the case of PST, a lack of experience in integrating technology in their teaching

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Contribution to the literature

- Identifies what knowledge related to the didactic dimension of the didactic-mathematical knowledge (DMK) conceptual framework is mobilized by pre-service teachers (PST) when integrating educational robotics (ER) in their mathematics teaching practices.
- The results of this study show the positive influence of the articulation between curricular knowledge, specific didactics, and the practicum for the development of the didactic knowledge of mathematics that PST needed to integrate ER in their teaching practices.
- In the context of this study, the articulation between mathematics and didactics curricular units with the practicum contributed to reducing PST's difficulties in creating lesson plans that integrate ER in teaching practices.

practices is also a constraint (Çebi et al., 2022). It is therefore necessary for initial teacher training (ITT) to address this issue, preparing PST to be competent in the appropriate integration of technology in teaching and learning processes (Çebi et al., 2022; Taimalu & Luik, 2019; Tondeur et al., 2016).

As technologies and technological devices have become increasingly available to teachers, the perception of their usefulness in promoting learning is growing in importance as an influencing factor in the decision to integrate certain technologies in their teaching practice (Lai et al., 2023). ER platforms are artefacts with the potential to promote meaningful learning (Athanasiou et al., 2019; Zhong & Xia, 2020), in particular learning associated with the development of computational thinking skills (Dong et al., 2023), science, technology, engineering, and mathematics (STEM) subjects (Kim et al., 2015; Sapounidis et al., 2023), and mathematics in particular (Uslu et al., 2022; Zhong & Xia, 2020). Despite the scientific community's interest in ER, there is no clear definition of the concept (Gavrilas et al., 2024; Scaradozzi et al., 2019; Sophokleous et al., 2021). Some authors define ER as a field of research focused on: a) promoting active learning through artefacts created by students and the phenomena they produce (Gabriele et al., 2012), and b) improving learning through the creation, implementation and validation of teaching practices (Benitti, 2012; Toh et al., 2016). For Misirli and Komis (2014), ER is a teaching practice in which students use robots to construct knowledge with the help of or for the robots themselves. In this study, supported by the conclusions of Scaradozzi et al. (2019), we adopt an understanding of ER as a didactic approach in which the technological component (robotics) plays an important role, so it is necessary for students to develop technological knowledge of the object in order to understand the meaning of the activity, transforming the robot into an epistemic tool.

In addition to common barriers in the integration of any other technology, the absence of curriculum guidelines and the lack of specific training for the development of teachers' didactic knowledge are two specific obstacles to the integration of ER in mathematics teaching and learning processes (Zhong & Xia, 2020). More countries are including ER as an optional component in the curriculum (Mangina et al., 2023). In Portugal, the context of this study, ER appears in the primary school mathematics curriculum associated with the development of computational thinking skills (Ministry of Education, 2021a, 2021b, 2021c, 2021d). Despite this recognized potential of ER, most existing studies are dedicated to programming ER platforms, and few address the integration of ER in mathematics teaching and learning processes (Sapounidis et al., 2023). As such, it is important that research into ER takes on pedagogical and didactic concerns (Jung & Won, 2018; Oliveira et al., 2023), seeking to understand how teachers integrate ER in their teaching practices to provide mathematical learning (Schina, Valls-Bautista, et al., 2021; Silva et al., 2024). This study is part of a larger work dedicated to the development of didactic knowledge necessary for appropriate integration of ER in tasks that promote mathematical learning and seeks to contribute to the discussion about how ITT programs can create the conditions for PSTs who teach mathematics to be able to adequately integrate ER in their teaching practices.

There are limitations on the curricular integration of ER (Kim, 2019; Sapounidis & Alimisis, 2021), particularly concerning mathematics teaching (Sapounidis et al., 2023), the creation of lesson plans that integrate ER in teaching practices (Schmid et al., 2021; Tankiz & Uslu, 2022) and the importance of PSTs experiencing the integration of ER in their teaching practices (Oliveira et al., 2023; Schina, Valls-Bautista, et al., 2021). As with any other technology, ITT programs dedicated to integrating ER in mathematics teaching and learning processes should provide situations where PSTs can develop and articulate their didactic knowledge in practical and contextualized situations (Santos & Castro, 2021). The design of initial mathematics teacher training programs should draw on educational theories, mathematics education research, and conceptual frameworks of mathematics didactic knowledge to justify decision-making (Font et al., 2022). This decision-making, particularly with regard to content-specific decisions, is strongly influenced by the teacher's knowledge (Pino-Fan et al., 2015; Shulman, 1986). Based on various studies dedicated to understanding mathematics teachers' competences and didactic knowledge, Pino-Fan et al. (2015) developed the conceptual framework DMK. According to this framework the iterative process of designing and analyzing teachers' actions (problems, practices, objects and processes) promotes the development of their didactic knowledge of mathematics (Pino-Fan et al., 2015). The use of the DMK conceptual framework as a support for structured reflection helps PSTs to make critical decisions during the design and implementation of mathematics teaching and learning processes (Breda et al., 2017).

Recognizing the importance of developing didactic knowledge of mathematics for PSTs who teach mathematics to appropriately integrate ER in their teaching practices, this study seeks to answer the following research question: What knowledge related to the didactic dimension of the DMK conceptual framework do PSTs mobilize when integrating ER in their mathematics teaching practice? To answer this research question, a training program was implemented that enabled PSTs to participate in mathematical tasks that integrate ER, and to create and implement lesson plans during the practicum for later reflection.

THEORETICAL BACKGROUND

Didactic Suitability Criteria

The appropriate integration of technology in mathematics education is a tripartite endeavor: didactic design, teacher performance and educational context (Drijvers, 2015). Besides being proficient in using the technological artefact, the teacher must also be able to mobilize didactic knowledge of mathematics (Blum et al., 2019; Pino-Fan et al., 2023) to create conditions that promote mathematical learning (Tabach & Trgalová, 2019). The complexity of the PST knowledge development process during training is well known (Ball et al., 2008; Gomes et al., 2022; Pino-Fan et al., 2023; Shulman, 1986) particularly when it is associated with the integration of technology (Costa et al., 2021; Tondeur et al., 2016). The DMK conceptual framework (Pino-Fan et al., 2015)–developed from the Onto-Semiotic Approach conceptual framework (Godino et al., 2007, 2022)–seeks to interpret the teacher's specialized knowledge, suggesting a categorization based on three dimensions (mathematics, didactics and meta didactics-mathematics), providing the conceptual support needed to analyze the teacher's actions (problems, practices, objects and processes). The onto-semiotic approach conceptual framework includes the concept of didactical suitability, according to which the process of teaching mathematics should be analyzed in terms of six dimensions: epistemic suitability, cognitive suitability, interactive suitability, media/resources suitability, emotional suitability and ecological suitability (Godino et al., 2007, 2022). The concept of didactic suitability is based on the relationship between the different dimensions involved in the design, implementation and assessment of mathematics teaching and learning processes (Godino, 2011). Following the framework, Breda et al. (2017) presented the set of didactical suitability criteria (DSC) as a tool for analyzing the teaching processes of mathematics teachers.

In the literature, there are various applications of DSCs as an analysis tool, mostly associated with reflections on the teaching practice of mathematics teachers. Within this subject, DSCs have been used to analyze the reflections of mathematics PSTs on simulations of mathematics teaching (Breda et al., 2021; Parra-Urrea & Pino-Fan, 2022), the mathematics teaching practice with the aim of developing skills in didactic analysis (Breda et al., 2017; Giacomone et al., 2018; Seckel & Font, 2020), as well as analyzing the reflections of future kindergarten teachers on the design of teaching sequences that integrate ER (Seckel et al., 2022). Breda (2020) sought to characterize how mathematics teachers justify the innovative nature of their mathematics teaching practices by looking at how they used DSCs to analyze their practice. The main results of that study show that teachers who analyzed their practice (design and intervention) used the DSC criteria in a more comprehensive and detailed way than teachers who did not implement their lesson plans.

Sala-Sebastià et al. (2022) analyzed the design of mathematical tasks and management of the teaching process by PSTs in early years mathematics, observing the presence of DSC indicators in their decision-making justifications. In a study by Hummes et al. (2023), the analysis of the effectiveness of a training program showed that mathematics teachers improved their reflection skills after using DSC to reflect on their teaching practice. Castro et al. (2018) present a guide for didactical reflection, created to help PSTs reflect on their intervention in the practicum. The data collected during the PSTs' performance made it possible to analyze their didactical-mathematical knowledge, suggesting that in addition to disciplinary and didactical knowledge, ITT needs to address emotional aspects of teacher/student interaction. Seckel et al. (2022) suggest including in ITT initiatives–supported by the six dimensions of DSC–that allow PSTs to experience the design and implementation of didactic sequences that integrate ER into mathematics teaching and learning processes.

The complex network of relationships, influences, and interactions between the DMK dimensions and components and the professional competences of mathematics teachers. This relation enables the use of didactic analysis to foster improvements in teaching practices by using the DSC to systematize the knowledge and competences identified in teachers' teaching practices, reflections and productions (Breda et al., 2017; Pino-Fan et al., 2023). Hummes and Seckel (2024) suggest that ITT programs that use DSC, in addition to teacher reflection, should also focus on the design and implementation of didactic sequences. The dimensions of the DMK conceptual framework can be used to analyze PSTs' knowledge mobilized during the design stages of teaching mathematical content: preliminary study, planning or design, implementation and assessment (Pino-Fan et al., 2015). In this study, the DSC (Breda et al., 2017) were used as a tool to analyze PST teaching practices during the integration of ER into the teaching and learning processes of mathematical content.

Educational Robotics in Initial Teacher Training and Integration of Educational Robotics in the Practice of Pre-Service Teachers

The characteristics of ER favor its integration in the teaching and learning processes of curricular content (Athanasiou et al., 2019; Zhong & Xia, 2020) and also favor interdisciplinarity (Kuhl et al., 2019; Miller & Nourbakhsh, 2016). More research is needed into the role of teachers in implementing curricular tasks that integrate ER (Tzagkaraki et al., 2021) and are dedicated to promoting mathematical learning (Sapounidis et al., 2023; Schina, Valls-Bautista, et al., 2021). Despite recognizing the potential benefits of ER, many teachers are still reluctant to integrate it in their teaching practices (Zhong & Xia, 2020). In ITT, programs that include the integration of ER in activities contribute to improvements in the acceptance of ER and perceived self-efficacy of PSTs, positively influencing their predisposition to integrate it into their future teaching practices (Schina, Valls-Bautista, et al., 2021; Silva et al., 2024). For ER to become an integral part of teaching practices, it needs to be part of teacher training (initial and ongoing) and for teachers to take an active role in studies on the integration of ER into teaching and learning processes (Arocena et al., 2022; Schina, Valls-Bautista, et al., 2021; Silva et al., 2024).

With the increasing inclusion of ER in curriculum guidelines (Mangina et al., 2023) grows the importance of understanding the integration of ER into the teaching practices of PSTs (Oliveira et al., 2023; Schina, Valls-Bautista, et al., 2021). It is also important to understand how participation in professional development initiatives improves PST skills in designing and implementing lesson plans that integrate ER in mathematics teaching and learning processes (Seckel et al., 2022; You et al., 2021). To create favorable conditions for mathematical learning to take place, teachers must be able to mobilize technological knowledge and didactic knowledge (Tabach & Trgalová, 2019). In the field of ER, growing didactic concerns have led to efforts to understand how to develop the didactic knowledge of PSTs needed to design lesson plans that integrate ER (e.g., Kim et al., 2015; Kucuk & Sisman, 2017) and how PSTs who teach mathematics establish mathematical connections in tasks that integrate ER (Souza et al., 2019). Research concerning the integration of ER in ITT has produced several recommendations for the design of training programs:

1. Allow PSTs first contact with ER platforms and the development of their technological knowledge and self-efficacy, facilitating the integration of ER into their future teaching practices (Anwar et al., 2019);
2. Allow PSTs to experience the integration of ER in practical and contextualized situations, so that they can develop didactic knowledge (Santos & Castro, 2021), helping them to understand the artefact's potential and restrictions, as well as its relationship with the curriculum (Huang & Zbiek, 2017);
3. Articulate training with the implementation of ER in their teaching practice (Anwar et al., 2019; Schina, Esteve-González, et al., 2021), allowing PSTs to create lesson plans that integrate ER (Kim et al., 2015; Seckel et al., 2022) and implement them during the practicum (Oliveira et al., 2023; Piedade et al., 2020) for later reflection (Pedro et al., 2019; Schina, Esteve-González, et al., 2021);
4. Long-term training programs that enable PSTs to create and implement lesson plans that integrate ER in the teaching of curricular content (Casler-Failing, 2021; Sapounidis & Alimisis, 2021), establishing favorable conditions for the development of PSTs' mathematical didactic knowledge needed to integrate ER in their teaching practices (Seckel et al., 2022). This allows it to work very well for a training in higher education learning ecologies (Moral-Sánchez et al., 2023);
5. Teacher support throughout the stages of designing and implementing lesson plans, in programs that include a theoretical, practical, reflective and specific didactic component (Schina, Esteve-González, et al., 2021);
6. Allow PSTs to interact with different ER platforms, as well as create conditions for PSTs to explore robots and associated resources (Alqahtani et al., 2022; Schina, Valls-Bautista, et al., 2021) and participate in collaborative problem-solving tasks (Piedade et al., 2020; You et al., 2021).

The decisions that shaped the design of the training program presented in this study were also influenced by the context in which it took place. In Portugal, a survey of the teaching community's training needs in programming and robotics identifies as areas of interest: specific training in ER, the construction of programmable robots and the design of lesson plans that allow these technologies to be integrated in the promotion of curricular learning (Ramos et al., 2022). These were integrated in the design of the pedagogical intervention presented in the next section.

MATERIALS AND METHODS

This study is a qualitative research of an interpretive nature (Cohen et al., 2018) that aims to identify what knowledge related to the didactic dimension of the DMK conceptual framework is mobilized by PSTs when integrating ER in their mathematics teaching practices. Since the training program calls for the design and implementation of lesson plans in a real classroom context and retrospective analysis, the research methodology followed the principles of research design (Cobb & Gravemeijer, 2008). Two iterative cycles of design, implementation and evaluation and a third cycle that does not include implementation (Plomp, 2013) are described in more detail in the following sections. This article presents and discusses the results of the data collection carried out during the second iterative cycle.

Participants

The multidisciplinary team conducting this study was composed of the first author (the teacher-researcher), two specialists in mathematics education, the third author who collaborated in data collection and was responsible for the construction of the multimodal narratives, and a specialist in educational technology. The training program took place in a 1st year class of a master's degree in primary education at a Portuguese higher education institution. The participants of this study were 19 PST, all female, and their participation was voluntary. They could withdraw at any time, and their anonymity was ensured through the confidential treatment of the data, respecting the conditions established in the ethics committee review. The 19 PST were distributed into 6 work groups–5 groups with three and 1 group with four participants–, keeping with the groups already established for the practicum, allowing to take advantage of the routines of collaborative work already established within each group.

Pedagogical Intervention

The intervention took place in the 2021/2022 academic year in two curricular units, one in mathematics (1st semester) and the other in mathematics didactics (2nd semester), in conjunction with the educational practice curricular unit (an annual subject covering the practicum). The design of the intervention sought to create favorable conditions for the development of PSTs' didactic knowledge of mathematics needed to design learning scenarios that integrate ER (Piedade et al., 2020; Schina, Esteve-González, et al., 2021).

1st semester

The part of the intervention planned for the first half of the year (from 29/10/2021 to 17/02/2022) had two objectives:

(i) to allow PSTs to experience the integration of ER in the teaching and learning processes of primary school mathematical content; and

(ii) to participate in the process of designing learning scenarios that integrate ER in the teaching of primary school mathematical content.

The intervention opened with two knowledge-building and development sessions. The first session served the purpose of discussing the theoretical principles underlying the integration of ER in mathematics teaching and learning processes. The second session focused on the principles governing the design and implementation of learning scenarios and their constituent elements: organizational design of the environment, roles and actors, storyline, work strategies, performances and proposals, and reflection and regulation (Matos, 2014; Pedro et al., 2019). Learning scenarios were chosen for the design of lesson plans in an attempt to reduce the influence of PSTs' lack of preparation in the design of lesson plans on the integration of ER into their teaching practices (Tankiz & Uslu, 2022) through the iterative and reflective process of design and implementation (Pedro et al., 2019).

This was followed by a set of four didactic sequences supported by three ER platforms of increasing complexity:

(1) the Super Doc robot, with tangible programming,

(2) the MindDesigner robot, which has a block-based programming environment and commands similar to those of the Super Doc, and

(3) in the last two didactic sequences two different constructions of the Ring:bit Kit were used with a block-based programming environment (MakeCode) similar to Scratch, which the participants had already explored in another curricular unit of the master's program.

The design of the set of didactic sequences aims to enable the PST to experience the integration of ER in practical and contextualized situations (Casler-Failing, 2021) that promote curricular articulation and integration (Kim, 2019; Sapounidis & Alimisis, 2021). All the didactic sequences followed the same format: after participating in a collaborative task that integrates ER (Anwar et al., 2019; You et al., 2021) in the learning of primary school mathematics content with connections to real-life problems (Zha et al., 2022), the learning scenario proposed by the teacher-researcher for the didactic sequence was adapted by the PST to the context of each group's practicum (Kim et al., 2015; Pedro et al., 2019; Seckel et al., 2022).

The work carried out in the first semester ended with the discussion of hypothetical learning scenarios created by each group. Throughout the semester, under tutorial guidance, each group developed a hypothetical learning scenario adapted to the context of the practicum, justifying the relevance of integrating the chosen ER

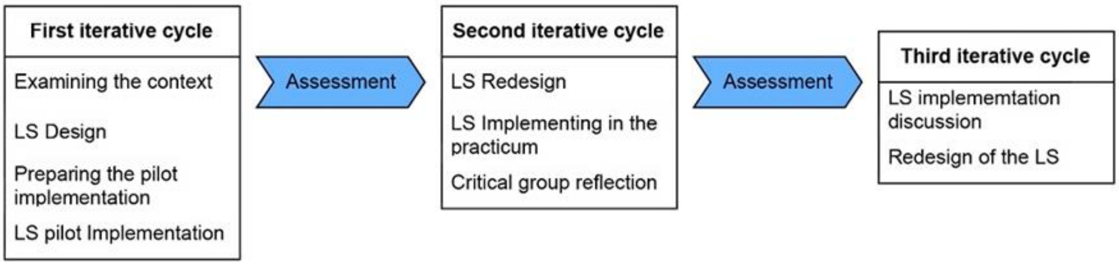


Figure 1. Iterative cycles of design and testing the learning scenarios (LS) (Source: Authors' own elaboration)

platform, strategies and methodologies for writing the constituent elements of the proposed learning scenario (Matos, 2014; Pedro et al., 2019). After the discussion, based on contributions from peers and the teacher-researcher, the groups assess the need to redesign their learning scenarios.

2nd semester

The second semester, from 16/03/2022 to 22/06/2022, began with a workshop for the cooperating teachers, with the PST groups also taking part. Its design aimed to allow the cooperating teachers to familiarize themselves with

(i) the ER platforms used in this study and

(ii) how the implementation of the learning scenarios created by the groups was expected to take place in the context of the practicum.

This was followed by two iterative cycles of design, implementation and evaluation and a third cycle that does not include implementation, summarized in **Figure 1**.

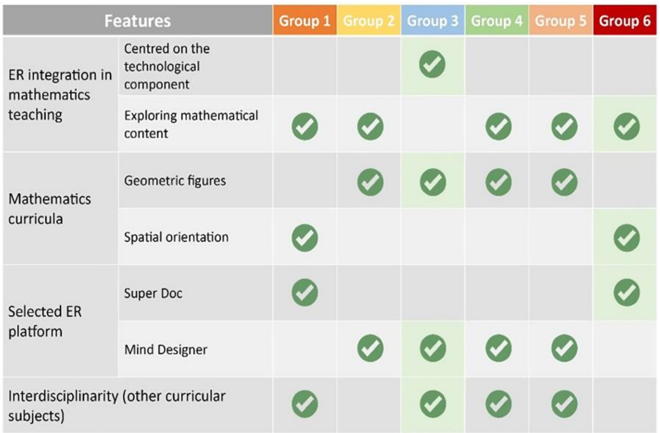
The first iterative cycle aimed to design learning scenarios for implementation in the practicum:

1. **Examining the context:** Based on the mathematics curriculum and each group's knowledge of the practicum class, situations were found that justify the integration of ER in tasks that promote mathematical learning (Sapounidis & Alimisis, 2021).
2. **Design:** Groups design learning scenarios for implementation in the practicum (Piedade et al., 2020; Tankiz & Uslu, 2022). This was monitored by the teacher-researcher during a 2-hour session in the classroom, with the rest being done autonomously.
3. **Assessment:** Once the design of the learning scenario was finalized, each group discussed their proposal with the teacher-researcher in tutorial orientation to prepare for the pilot implementation (Cevikbas et al., 2023). The aim was to reduce the impact of a lack of preparation in the creation of lesson plans on the integration of ER into PST teaching practices (Tankiz & Uslu, 2022), by creating the conditions for PSTs to take an active role in the reflective process of designing learning scenarios that integrate ER in mathematics tasks with the support of the teacher-researcher.
4. **Pilot implementation:** Each group implemented their learning scenario in a simulated classroom with their peers. In addition to allowing the groups to test their learning scenarios, this set of six sessions also served to enable the PSTs to experience classroom management that integrates ER (Casler-Failing, 2021) and observe their peers in similar conditions (Schina, Valls-Bautista, et al., 2021). At the end of each pilot implementation, a critical discussion took place. The groups collected input from their peers and the teacher-researcher for further reflection, assessing the need for redesign (Pedro et al., 2019).

The second iterative cycle aimed to redesign the learning scenarios and implement them in practicum:

1. **Redesign:** Based on a reflection on the pilot implementation, the learning scenarios were redesigned (Matos, 2014; Piedade et al., 2020) in tutorial orientation (Cevikbas et al., 2023).
2. **Implementation:** In articulation with the educational practice curricular unit, the learning scenarios resulting from the redesign were implemented with the practicum class (Kucuk & Sisman, 2017; Piedade et al., 2020); once the implementation was complete, it was discussed with the teacher-researcher.
3. **Critical group reflection:** Written critical reflection by each group on the process of designing and implementing the learning scenarios in the practicum (Piedade et al., 2020; Schina, Esteve-González, et al., 2021).

The third iterative cycle corresponds to the redesign of the learning scenarios after their implementation in the practicum. Once all the groups had finalized their implementations, a discussion took place. Each group presented the learning scenario created for implementation and shared their reflections on the operationalization in the practicum. These were subject to critical discussion with their peers and the teacher-researcher, with each group collecting the contributions they considered pertinent so that, together with their reflections, they could proceed to redesign the learning scenarios.



Features		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
ER integration in mathematics teaching	Centred on the technological component			✓			
	Exploring mathematical content	✓	✓		✓	✓	✓
Mathematics curricula	Geometric figures		✓	✓	✓	✓	
	Spatial orientation	✓					✓
Selected ER platform	Super Doc	✓					✓
	Mind Designer		✓	✓	✓	✓	
Interdisciplinarity (other curricular subjects)		✓		✓	✓	✓	

Figure 2. Characteristics of the learning scenarios implemented by the groups in the practicum (Source: Authors' own elaboration)

Data Collection

To answer the research question of this study, it was necessary to analyze the performance of the PSTs during the implementation of the learning scenarios in the practicum. Data collection in the second iterative cycle followed the protocol for preparing multimodal narratives, an "instrument which gathers, aggregates, organizes and transforms classroom data about teaching practice in science and technology lessons to produce a complete and concise document that may subsequently be analyzed, avoiding the difficulty of handling multiple data sources" (Lopes et al., 2014, p. 416). In this way, by compiling different sources (audio, video, field notes, task statements and student productions), data triangulation was ensured (Cohen et al., 2018). Although all the groups were monitored equally throughout the intervention, two groups were chosen for analysis because they were considered to be representative of the work carried out by the class. **Figure 2** summarizes the features of the learning scenarios presented by the 6 groups.

The learning scenario designed by group 1 aimed at exploring the mathematical content money, proposing an integration of ER (programming a robot to run through an itinerary) that also took advantage of tasks aimed at promoting financial literacy, which in Portugal takes place under the subject citizenship education. Group 2 proposed to integrate ER into the teaching of the mathematical content Area of squares and rectangles by programming robots to draw geometric figures. Group 3's proposal differed from the others in its type of ER integration, implementing a learning scenario that aimed to create a comic strip using the robot to draw the panels (squares and rectangles) by changing the dimensions of the sides of the panels in the robot's programming. Group 4, having identified a difficulty in the class related to perceptual constancy, presented an integration of ER that created conditions for students to change the position of the geometric figures created with the robot (squares, rectangles and triangles), concluding that their properties do not change with their position, and then used the geometric figures to collaboratively create a short, illustrated story. Group 5 aimed to systematize learning related to Concurrent, perpendicular and parallel lines, presenting an interdisciplinary approach that used the robot to draw parallel and perpendicular streets, where students would include spaces that can usually be found in cities or villages, discussing their differences within the guidelines proposed for the subject of social studies. Group 6 also identified a difficulty in the class (related to laterality), proposing to integrate ER into mathematical tasks exploring the content of spatial orientation and mental arithmetic strategies, with students using the robot to run an itinerary and stopping at different points to solve addition and subtraction operations using mental arithmetic.

The multimodal narratives of the implementations of group 3 (Gr3) and group 6 (Gr6) were chosen to be analyzed, as this way a diversity of features can be included while at the same time making it feasible to present the results given the high volume of data generated.

Data Analysis

We carried out a content analysis (Krippendorff, 2019) of the multimodal narratives using the MAXQDA software (Kuckartz & Rädiker, 2019) in the coding and categorization stages. As explained in theoretical background, the DSCs guided the content analysis. The units of analysis (text segments, sentences or paragraphs) were individualized for categorization.

Table 1 shows the categories, components and respective codes for each of the DSCs established by Breda et al. (2017) and used in this study. Excerpts from sentences, phrases and blocks of dialogue were established as units of analysis.

Table 1. DSC categories, components and codes (Breda et al., 2017)

Category	Components	Code
Epistemic suitability (Ep)	Errors	Ep1–Practices considered mathematically incorrect are not observed
	Ambiguities	Ep2–Ambiguities that could confuse students are not observed; definitions and procedures are clear and correctly expressed, and adapted to the target level of education; explanations, evidence and demonstrations are suitable for the target level of education, the use of metaphors is controlled, etc.
	Diversity of processes	Ep3–Relevant processes in mathematical activity (modelling, argumentation, problem solving, connections, etc.) are considered in the sequence of tasks.

Table 1 (Continued). DSC categories, components and codes (Breda et al., 2017)

Category	Components	Code
	Representation	Ep4–The partial meanings (constituted of definitions, properties, procedures, etc.), are representative samples of the complexity of the mathematical notion chosen to be taught as part of the curriculum. Ep5–For one or more partial meanings, a representative sample of problems is provided. Ep6–The use of different modes of expression (verbal, graphic, symbolic, etc.), treatments and conversations amongst students are part of one or more of the constituents of partial sense.
Cognitive suitability (C)	Previous knowledge	C1–Students have the necessary previous knowledge to study the topic. C2–The intended meanings (reasonable difficulty) can be taught through its diverse components.
	Adaptation of the curriculum to the individuals' different needs	C3–Development and support activities are included.
	Learning	C4–The diverse methods of evaluation demonstrate the application of intended or implemented knowledge/competences.
	High cognitive demand	C5–Relevant cognitive processes are activated (generalization, intra-mathematical connections, changes of representations, speculations, etc. C6–Metacognitive processes are promoted.
Interactional suitability (I)	Teacher/student interactions	I1–The teacher appropriately presents the topic (clear and well-organized presentation, not speaking too fast, emphasis on the key concept of the topic, etc. I2–Students' conflicts of sense are recognized and resolved (students' silence, facial expressions, questions are correctly interpreted, and an appropriate survey is conducted, etc. I3–The aim is to reach a consensus on the best argument. I4–Varieties of rhetorical and rational devices are used to involve the students and capture their attention. I5–The inclusion of students into the class dynamic is facilitated–exclusion is not.
	Interaction amongst learners	I6–Dialogue and communication between students is encouraged. I7–Inclusion in the group is preferred and exclusion is discouraged.
	Autonomy	I8–Moments in which students take on responsibility for their study (exploration, formulation and validation) are observed.
	Formative evaluation	I9–Systematic observation of the cognitive progress of the students.
Mediational suitability (M)	Material resources (manipulatives, calculators, computers)	M1–The use of manipulatives and technology, which give way to favorable conditions, language, procedures, and arguments, adapted to the intended sense. M2–Definitions and properties are contextualized and motivated using concrete situations, models, and visualizations.
	Number of students, scheduling, classroom conditions	M3–Number and distribution of students enables the desired teaching to take place. M4–Timetable of course is appropriate (for example, not all the classes are held late. M5–The classroom and the distribution of the students is appropriate for the development of the intended instructional method.
	Time (for group teaching/tutorials; time for learning)	M6–Accommodating the intended/implemented content to the available time (contact or non-contact hours). M7–Devotion of time to the most important or central aspects of the topic. M8–Devotion of time to topic areas that present more difficulty.
Affective suitability (A)	Interests and needs	A1–The selection of tasks that are of interest to the students. A2–Introduction of scenarios that enable students to evaluate the practicality of mathematics in everyday situations and professional life.
	Attitudes	A3–Promoting involvement in activities, perseverance, responsibility, etc. A4–Reasoning should be done so in a context of equality; the argument will be valued in its own right and not by the person who puts it forward.
	Emotions	A5–Promotion of self-esteem, avoiding rejection, phobia or fear of mathematics. A6–Aesthetic qualities and the precision of mathematics are emphasized.

Table 1 (Continued). DSC categories, components and codes (Breda et al., 2017)

Category	Components	Code
Ecological suitability (Ec)	Adaptation to the curriculum	Ec1–The content, its implementation and evaluation, correspond to the curricular plan.
	Intra/Interdisciplinary connections	Ec2–The content is related to other mathematical topics (connection of advanced mathematics with curricular mathematics and the connection between different mathematics content covered in the curriculum) or to the content of other disciplines, (an extra-mathematical context or rather links with other subjects from the same educational stage).
	Social-professional practicality	Ec3–The course content is useful for socio-professional insertion.
	Didactical Innovation	Ec4–Innovation based on reflexive research and practice (introduction of new content, technological resources, methods of evaluation, classroom organization, etc.).

The principles of context units were followed by making thematic distinctions and trying to identify the meanings of the interlocutors' ideas in the recording units to proceed with coding (Krippendorff, 2019). The frequencies of the codes and their co-occurrences were analyzed. The distribution of the codes and their association allows to infer that the connotation of the meanings associated with the units of analysis is present in the sender (Kuckartz & Rädiker, 2019). Coding was carried out by the first author.

The features of the documents analyzed make it pertinent to clarify some details about the coding process. The characteristics of the errors component (EP1–Practices considered mathematically incorrect are not observed) dictated that the units of analysis for this component were the content of the episodes of the multimodal narratives (Lopes et al., 2014), which meant that this code was not included in the analysis of co-occurrences. In the context of this study, regarding the coding proposed by Breda et al. (2017), only ER platforms were considered as resources for descriptors M1, M2, and Ec4, and for descriptor Ec1 only the mathematics curriculum.

Each group's multimodal narrative was divided into two documents in the MAXQDA software (Kuckartz & Rädiker, 2019), creating two sets of documents (Gr3 and Gr6) containing the first main part (context information) and the episodes. Since the aim was to analyze the actions of the PSTs during the implementation of the learning scenarios in the practicum, the co-occurrence analysis was carried out only on the episodes of the multimodal narrations, since these show the actions of the teachers and students, as well as their productions and the language used (Lopes et al., 2014). Given that the DSCs stem from the onto-semiotic approach and the relationships between its components, the co-occurrences between DSC codes allow a more detailed analysis and understanding of the PSTs' knowledge. The data was coded, and the units of analysis were categorized. The next step was to analyze frequency and co-occurrences, which made it possible to create the frequency graphs and the co-occurrences graphs. We chose graphs that represent the number of co-occurrences between each code, translated by the thickness of the lines connecting them, making it easier to visualize the data in the tables in **Appendix A** (co-occurrences in Gr3) and **Appendix B** (co-occurrences in Gr6).

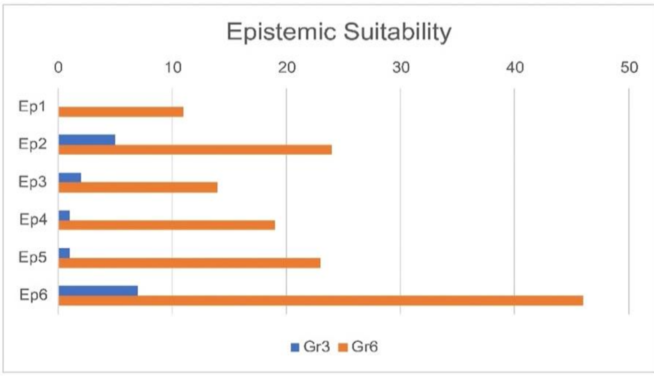


Figure 3. Frequency of the components of epistemic suitability (see **Table 1** for code descriptions) (Source: Authors' own elaboration)

RESULTS

The following section presents the results for the two sets of documents analyzed (Gr3 and Gr6). We first show the results for the frequency of DSC codes for each of the categories: epistemic, cognitive, interactional, mediational, affective and ecological. After that we show the results for the co-occurrence of DSC codes in each of the sets of documents.

Frequency of DSC Components

The frequency distribution of the codes in the epistemic suitability category is shown in **Figure 3**. In Gr3 there are occurrences of almost all the epistemic suitability components, except for Ep1, while all the components are present in Gr6. The absence of Ep1 in Gr3 means that incorrect practices have been identified from a mathematical point of view. All the components are more frequent in Gr6. This difference between the two sets of documents analyzed shows that there is a greater number of occurrences of units of analysis referring to the teaching of mathematical content in

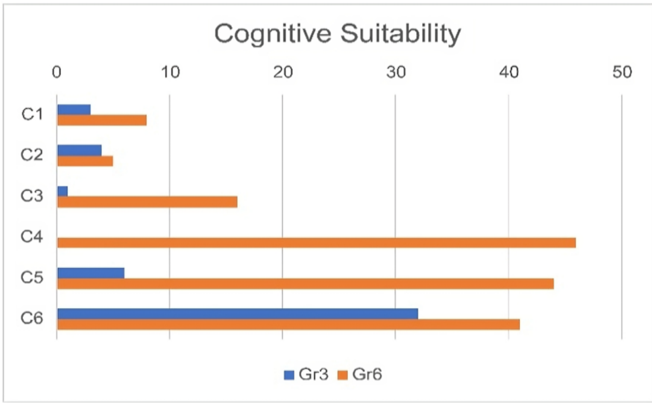


Figure 4. Frequency of the components of cognitive suitability (see **Table 1** for code descriptions) (Source: Authors' own elaboration)

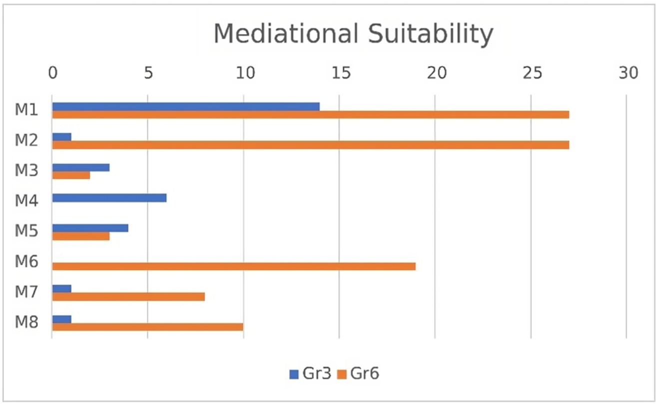


Figure 6. Frequency of the components of mediational suitability (see **Table 1** for code descriptions) (Source: Authors' own elaboration)

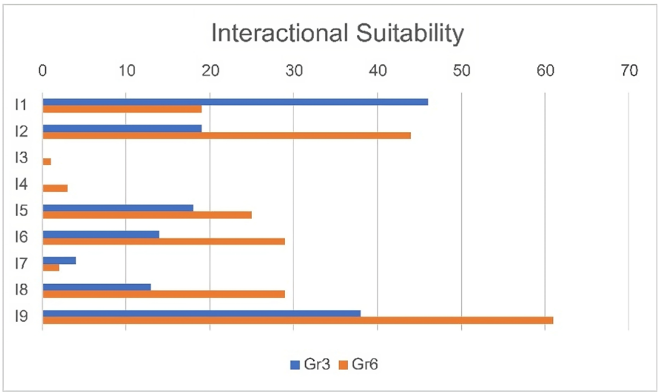


Figure 5. Frequency of the components of interactional suitability (see **Table 1** for code descriptions) (Source: Authors' own elaboration)

accordance with the curriculum in Gr6. Regarding the use of relevant processes in mathematical activity (Ep2), the greater number of occurrences in Gr6 is evident, as are the occurrences related to representation (Ep4, Ep5, and Ep6). The occurrences related to the use of different forms of representation and changes in representation (Ep6) show the most striking difference between Gr3 and Gr6.

Figure 4 shows the results for the cognitive suitability category. As with the epistemic suitability category, Gr6 had a higher number of occurrences compared to Gr3. All the components of cognitive suitability were present in Gr6, while there were no occurrences of C4 in Gr3. The number of occurrences of C1 and C2 (similar in both sets of documents) shows that there is evidence in the PST teaching practices related to the student's prior knowledge. On the other hand, concerning coding related to adapting tasks with a curricular framework to the students' characteristics (C3), almost all of the occurrences are in Gr6, with only one occurrence in Gr3. Regarding the inclusion of assessment strategies to gauge student learning (C4), there are only occurrences in Gr6. The majority of occurrences of coding related to the promotion of relevant cognitive processes (C5) are found in Gr6 (44), with Gr3 showing only a small number (6 occurrences). The graph shows that Gr3 and Gr6 have a similar number of occurrences related to promoting metacognitive processes (C6).

As with the previous categories, the graph in **Figure 5** shows that all the components of the interactional suitability category are present in Gr6, but not in Gr3. Most of the components have a higher number of occurrences in Gr6, except for I1 (the teacher appropriately presents the topic) and I7 (promoting the inclusion of students in the group). These results show a greater number of occurrences in Gr6 concerning the PSTs' teaching practices in dynamic classroom management (I2 and I4), the interaction between students (I3, I5, and I6) and formative assessment moments (I9); promoting student participation in classroom dynamics (I5) and student autonomy (I8).

Figure 6 summarizes the results for the mediational suitability category. The majority of occurrences are found in Gr6, with no occurrences of M6 identified in Gr3 or M4 in Gr6. Gr6 shows a greater number of occurrences related to the integration of ER in mathematics teaching processes (M1 and M2) and occurrences related to the time component (M6, M7 and M8). As for occurrences related to the organization of classroom logistics and students (M3, M4, and M5), they appear in greater numbers in Gr3.

The results of the affective suitability category, which has the lowest number of overall occurrences of all the categories, are shown in **Figure 7**. The highest number of occurrences in this category related to selecting tasks that interest students (A1) is found in Gr6, with only one occurrence in Gr3. There were no occurrences related to proposing situations that allowed students to realize the usefulness of mathematics in a real context (A2). There are a similar number of occurrences in Gr3 and Gr6 related to promoting student involvement in tasks (A3). There was only one occurrence in Gr6 related to managing interaction and argumentation between students (A4). As for occurrences related to the Emotions component, only three occurrences of situations

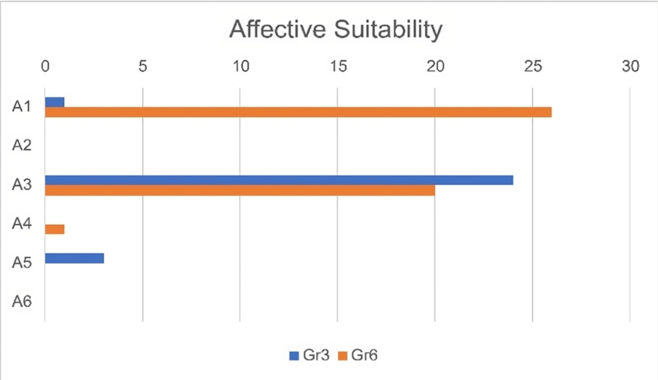


Figure 7. Frequency of the components of affective suitability (see **Table 1** for code descriptions) (Source: Authors' own elaboration)

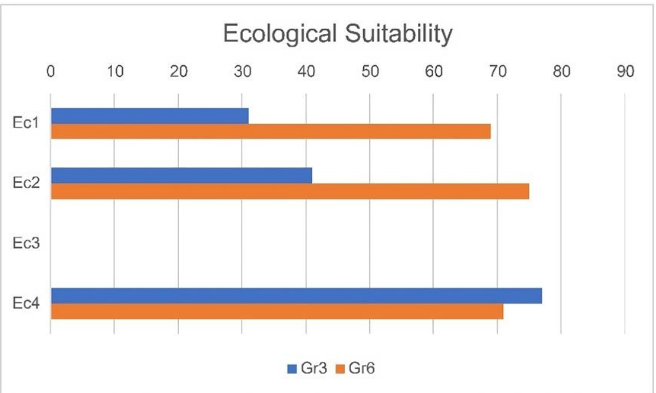


Figure 8. Frequency of the components of ecological suitability (see **Table 1** for code descriptions) (Source: Authors' own elaboration)

involving the promotion of self-esteem (A5) were identified in Gr3.

With the highest number of occurrences of all the categories, the results for the ecological suitability category are shown in the graph in **Figure 8**. Only three components are identified in Gr3 and Gr6 (Ec1, Ec2 and Ec4). Occurrences related to adaptation to the mathematics curriculum (Ec1) appear in greater numbers in Gr6, with approximately double the occurrences in Gr3, as do occurrences related to situations that make it possible to establish mathematical and interdisciplinary connections (Ec2). No occurrences were identified that show the relationship between the mathematical content proposed by the PST and socio-professional integration (Ec3). Gr3 and Gr6 show a similar number of occurrences related to the inclusion of didactic innovation in PST teaching practices (Ec4), most of which relate to the integration of ER in the teaching and learning of mathematics.

Co-Occurrence of DSC Components

This section is dedicated to presenting the main results relating to the co-occurrences identified in the Gr3 and Gr6 document sets.

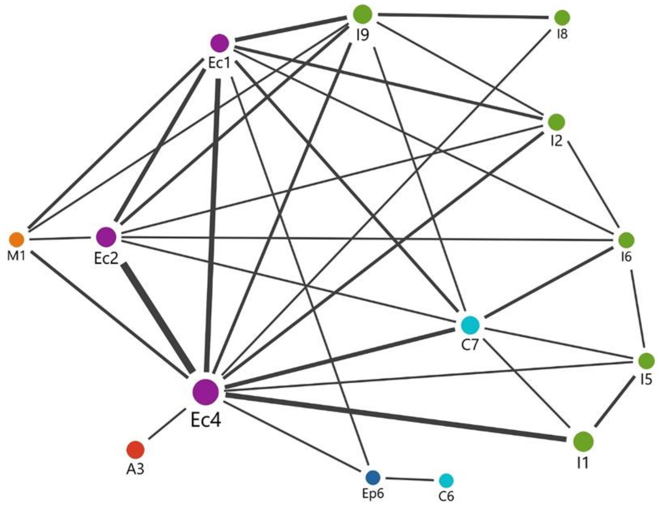


Figure 9. Co-occurrence of DSC components in group 3 (Gr3) (see **Table 1** for code descriptions) (Source: Authors' own elaboration)

Co-occurrence of DSC components in Gr3

Figure 9 summarizes the main co-occurrences identified in Gr3 (minimum of 5 co-occurrences between codes). The graph represents the number of co-occurrences between each code, translated by the thickness of the lines connecting them and the size of the nodes, making it easier to visualize the data in **Table A1** in **Appendix A**. The number of co-occurrences between components of different categories is higher than the number of co-occurrences between components of the same category. The highest number of co-occurrences is between components of the Interactional and ecological suitability categories (120), suggesting that there is an association between interactions within the classroom and adaptation of the teaching process to the mathematics curriculum and context. The number of co-occurrences identified between components of the cognitive suitability category and components of the Interactional (43) and ecological suitability (44) categories is also relevant, suggesting an association in PST teaching practices regarding promoting learning processes with interactions within the classroom and adaptation of the teaching process to the mathematics curriculum and context.

The highest number of co-occurrences identified, Ec2/Ec4 (23), shows that there is an association between mathematical/interdisciplinary connections and didactic innovation in PST teaching practices, most of which concern the integration of ER into mathematics teaching and learning processes. The co-occurrences between Ec1/Ec2 (13) and Ec1/Ec4 (16) reinforce the evidence related to the ecological suitability category in PST teaching practices, showing that there is an association between adaptation to the mathematics curriculum (Ec1) and promotion of intra/interdisciplinary connections (Ec2) and didactic innovation (Ec4).

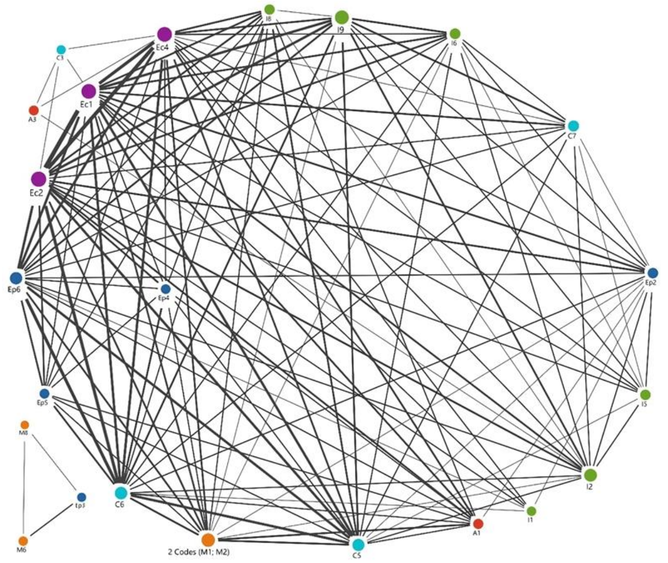


Figure 10. Co-occurrence of DSC components in group 6 (Gr6) (see **Table 1** for code descriptions) (Source: Authors' own elaboration)

Most of the co-occurrences identified relate to components of the ecological suitability category. Within the cognitive suitability category, the highest number of co-occurrences (16) was identified between the component related to the promotion of cognitive processes (C6) and the component related to didactic innovation (Ec4). In the interactional suitability category, the co-occurrences I9/Ec4 (11), and I9/Ec1 (13) show that there is an association between formative assessment and didactic innovation, as well as with adaptation to the mathematics curriculum. In the mediational suitability category, with 8 co-occurrences each, M1/Ec1 and M1/Ec4 stand out as evidence of a relationship between the integration of ER in mathematics teaching processes, adaptation to the mathematics curriculum and didactic innovation in PST teaching practices. With even lower values, the co-occurrences A3/Ec4 (5) and Ep6/Ec4 (5) show little evidence of an association between didactic innovation, promotion of student involvement in tasks and use of different forms of representation and changes in representation in PST teaching practices.

Co-occurrence of DSC components in Gr6

The co-occurrences identified in Gr6 are summarized in **Figure 10** (minimum of 5 co-occurrences between codes). The graph represents the number of co-occurrences between each code, translated by the thickness of the lines connecting them and the size of the nodes, making it easier to visualize the data in **Table B1** in **Appendix B**. As in Gr3, there are also a greater number of co-occurrences in Gr6 between components of different categories than between components of the same category. Of these, the co-occurrences of ecological suitability components with epistemic suitability (248), cognitive suitability (239) and interactional suitability (316) stand out, suggesting that there is an association between context, adaptation of the teaching process to the mathematics curriculum and context, promotion of learning processes and interactions within the classroom. Also relevant are the co-occurrences of cognitive suitability with epistemic suitability (202), and interactional suitability (227), suggesting that there is an association between promotion of learning processes, adaptation of the teaching process to the mathematics curriculum and context, and interactions within the classroom.

The highest number of co-occurrences is between components of the ecological suitability category (Ec1/Ec2 (51), Ec2/Ec4 (47), and Ec1/Ec4 (37)) showing that, as in Gr3, there is an association between adapting to the mathematics curriculum (Ec1), promoting situations that allow mathematics and interdisciplinary connections to be established (Ec2), and didactic innovation (Ec4). With slight differences in the values of the co-occurrences, a pattern of cross-category co-occurrences is identified involving Ec1 (443), Ec2 (455), Ec4 (390), C4 (321), C5 (355), Ep6 (360) and A1 (209). It is clear from the PST teaching practices that there are relationships between adapting to the mathematics curriculum (Ec1), representation (Ep4 and Ep6), including assessment strategies to gauge student learning (C4 and I9), high cognitive demand (C5 and C6), classroom management (I2 and I6), promoting student autonomy (I8), integrating ER into mathematics teaching processes (M1 and M2), and developing tasks that are of interest to the students (A1). There is also an isolated group of co-occurrences, evidence of an association between the PST's actions in time management (M6 and M8) and the use of important processes in mathematical activity (Ep3) in the implementation of the sequence of tasks proposed in the learning scenarios.

Co-occurrence of DSC categories

Figure 11 shows a comparison between the co-occurrences of categories in Gr3 and Gr6. We can see the greater number of co-occurrences in Gr6, as well as the greater complexity of these relationships. In Gr6 there are co-occurrences between all the categories, which is not the case in Gr3 particularly in the affective suitability category. Also relevant is the greater influence of epistemic, cognitive and mediational suitability identified in Gr6 compared to Gr3.

We note that in both Gr3 and Gr6 the mobilization of knowledge of curricular, contextual, social, political or economic aspects that influence the management of student learning (ecological suitability) has the highest co-occurrence values of all the categories. This is followed by the co-occurrence of units of analysis related to knowledge of the interactions that take place within a classroom (interactional suitability) and related to

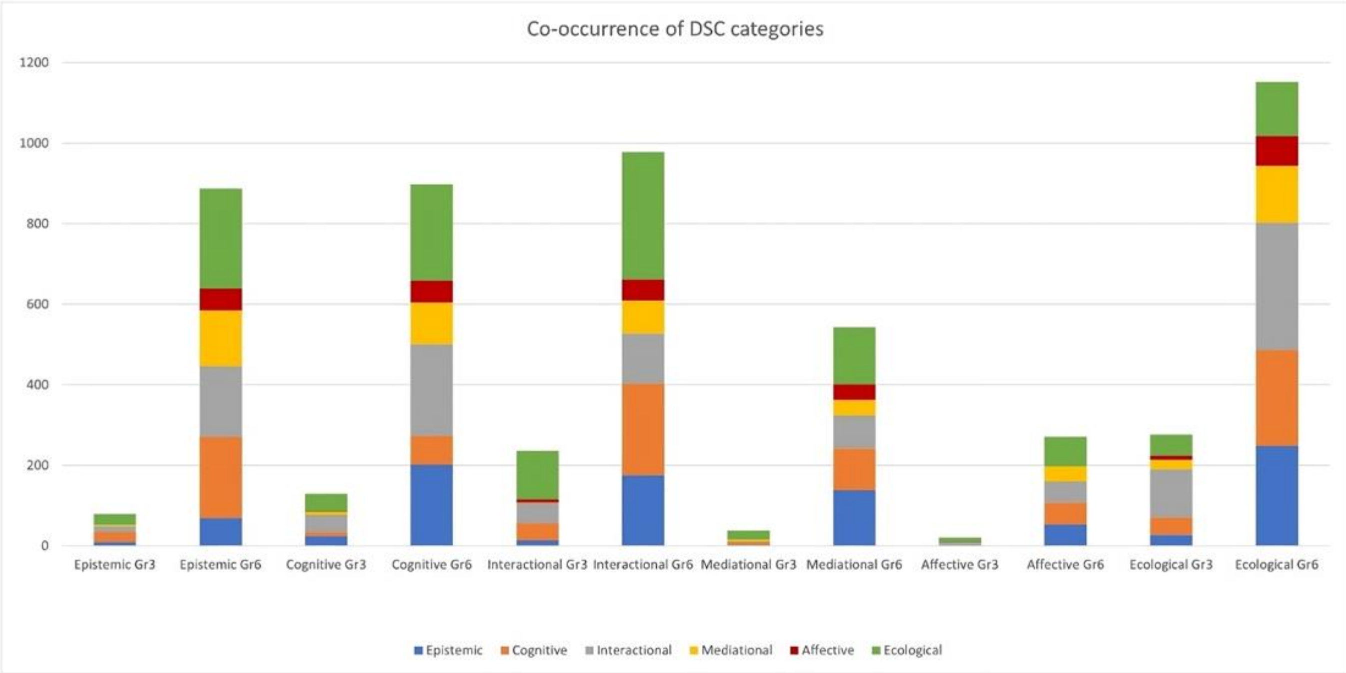


Figure 11. Global co-occurrence of DSC categories in group 3 (Gr3) and group 6 (Gr6) (Source: Authors' own elaboration)

knowledge of students' cognitive aspects (cognitive suitability). The co-occurrence of units of analysis related to the mobilization of specialized knowledge of the mathematical dimension (epistemic suitability) differs between Gr3 and Gr6. While in Gr3 the number of co-occurrences in the epistemic suitability category are about half of those in the cognitive suitability category, in Gr6 they are almost identical to the number of co-occurrences in the interactional suitability category, with the third highest value in Gr6.

DISCUSSION

This study has sought to understand how ITT programs can help PSTs who teach mathematics to adequately integrate ER in their teaching practices. It sought to identify the knowledge related to the didactic dimension of the DMK conceptual framework mobilized by PSTs when implementing lesson plans that integrate ER during the practicum. The content analysis of the multimodal narratives from group 3 and group 6, using the theoretical construct of didactic suitability, made it possible to identify the DSC present in the sets of documents analyzed. The results presented are discussed here in terms of the relationship between the DSC and the categories of the didactic dimension of the DMK conceptual framework (Breda et al., 2017), since the theoretical tools of the DMK allow to infer what knowledge is present in the PST teaching practices (Font et al., 2022). The results presented show a greater number of occurrences and co-occurrences in Gr6. By identifying the knowledge related to the didactic dimension of the DMK conceptual framework mobilized by the PSTs, we claim that the results of this study offer a contribution to the discussion about the integration of ER in the practices of PSTs to promote mathematical learning. The main contribution of these results concerns some of the limitations pointed out about the curricular integration of ER (S. A. Kim, 2019; Sapounidis & Alimisis, 2021), in particular concerning the need for more research into teachers' teaching practices when implementing curricular tasks that integrate ER (Tzagkaraki et al., 2021) and dedicated to promoting mathematical learning (Sapounidis et al., 2023; Schina et al., 2021b).

The results of the epistemic suitability category show a greater number of occurrences in Gr6, as well as the presence of all its components, while no occurrence of Ep1 was identified in Gr3. This shows that the PST mobilized the mathematical knowledge needed to teach (Pino-Fan et al., 2018).

As for the results relating to the cognitive suitability category, it is argued that the low number of occurrences of C1, C2, and C3 identified in Gr3 are due to the known difficulty of PSTs adapting the structural elements of the planning to the specific characteristics and needs of the students (König et al., 2020). The lack of occurrences of C4, on the other hand, is thought to have been influenced by group 3's decision to use the data resulting from the exploration of the mathematical content in previous lessons to program the robots, limiting the PSTs' use of situations to assess the students' learning. We argue that this decision, together with the lack of experience in integrating ER into their teaching practices (Çebi et al., 2022) led to the PSTs focusing solely on monitoring the manipulation and programming of the robot, without taking advantage of opportunities to establish connections between the programming done by the students and the mathematical content. This was particularly evident when monitoring learning. Overall, the evidence in Gr3 and Gr6 shows that the PST mobilized the students' knowledge of cognitive aspects (Pino-Fan et al., 2018).

The interactional suitability category refers to knowledge related to the management of interactions in the classroom during teaching and learning processes (Pino-Fan et al., 2018). The evidence shows that the PSTs mobilized this knowledge during their teaching practices since most of the components were identified in Gr3 and Gr6. It is thought that the low number of occurrences of I3 and I4 is due to the complexity of orchestrating discussions, associated with the lack of experience of PSTs in conducting these moments (Stein et al., 2008). We argue that the greater number of occurrences of I1 and I7 in Gr3, contrary to the pattern identified in most of the components, is due to the fact that group 3 focused on the technological component, with more occurrences related to the indications needed to program the robots.

The mediational suitability category concerns knowledge of resources and how their integration into the teaching process can influence learning processes (Pino-Fan et al., 2018). The analysis of the results of this category (with most components occurring in both Gr3 and Gr6), allows us to state that the PSTs mobilized this knowledge in their teaching practices. We argue that the high number of occurrences of M1 and M2 in Gr6 is due to the choice to explore the mathematical content in parallel with the operationalization of the robots. The number of occurrences related to time management (M6, M7 and M8) is thought to be influenced by the pilot implementation, in which the PSTs had the opportunity to gauge the importance of time management in mathematics tasks that integrate ER.

In addition to having the lowest number of occurrences of all the categories, not all the components of affective suitability are present. As such, it is not possible to say that PST mobilized knowledge related to students' affective, emotional and behavioral aspects (Pino-Fan et al., 2018).

The ecological suitability category relates to knowledge of the mathematics curriculum, its connections with other curricula and the context in which it is implemented (Pino-Fan et al., 2018), and has the highest number of occurrences of all the categories. The existence of occurrences of most of the components in Gr3 and Gr6 allows us to affirm that the PST mobilized this knowledge in their teaching practices. The results of the analysis of the design of mathematics tasks by PSTs presented by Sala-Sebastià et al. (2022) report the absence of indicators relating to mathematical/interdisciplinary connections (Ec2). It is argued that, in this study, the high number of occurrences of Ec2 identified in Gr3 and Gr6 is influenced by the inclusion of ER in the Portuguese mathematics primary school curriculum and the integration of ER in the exploration of mathematical content, as well as the choice of group 3 to take advantage of interdisciplinarity in the design of their learning scenario, a characteristic of ER that facilitates establishing connections between different curricular contents (Kuhl et al., 2019; Miller & Nourbakhsh, 2016). The high number of occurrences of Ec4 was to be expected since one of the characteristics of didactic innovation is the integration of technological resources (Breda, 2020) such as ER platforms.

The co-occurrences identified are discussed below. The direct relationship between the cognitive and affective suitability categories (Castro et al., 2018) makes it possible to better understand mathematics teachers' knowledge of students' cognitive processes and management of interactions when solving mathematics tasks (Pino-Fan et al., 2015). This relationship encompasses and expands Shulman's concept of knowledge of learners and their characteristics (Shulman, 1987), and Knowledge of content and students proposed by Ball et al. (2008). According to Pino-Fan et al. (2015), the relationship between the Interactional and mediational suitability categories encompasses and expands on the idea of knowledge of content and teaching proposed by Ball et al. (2008). The evidence presented shows that there are co-occurrences between different components of the cognitive and affective suitability categories, as well as between components of the interactional and mediational suitability categories, which allows us to state that the PST mobilized this knowledge during their teaching practices.

The pattern of co-occurrences identified in Gr6 (which also exists in Gr3, but with fewer occurrences) is evidence that group 6, by mobilizing didactic and technological knowledge, created conditions favorable for mathematical learning (Tabach & Trgalová, 2019) by integrating ER in their mathematics teaching practices (Sapounidis et al., 2023). The co-occurrences between epistemic suitability, ecological suitability, cognitive suitability, and mediational suitability show that there is an association between the knowledge needed to teach mathematics, knowledge of curricular and contextual aspects, knowledge of students' cognitive aspects and knowledge of the resources and means that can foster students' learning process. These co-occurrences are evidence of the permeable boundaries and interactions between the different categories of didactic suitability, as already pointed out by Godino (2011). We argue that the co-occurrences related to the integration of ER in mathematical tasks, in accordance with the curriculum, reflect characteristics of the proposed training program. Participation in tasks that promote mathematical learning and integrate ER (Sapounidis et al., 2023; Schina, Valls-Bautista, et al., 2021) and the process of designing and implementing learning scenarios in the practicum (Piedade et al., 2020; Tankiz & Uslu, 2022) contributed to the PST mobilizing knowledge related to the didactic dimension of the DMK conceptual framework.

Implications for ITT

Without claiming to generalize the results of this study, given the size of the sample and its specific context, we believe that this study has implications for the integration of ER into ITT. A training program is presented that seeks to mitigate known difficulties in integrating technology into ITT, such as beliefs, attitudes and knowledge of PSTs (Wilson, 2023). Known limitations of integrating ER into mathematics teaching and learning processes also influenced the design of the training program, such as: the lack of specific training for the development of teachers' didactic knowledge (Zhong & Xia, 2020), the design of lesson plans that integrate ER in teaching practices (Schmid et al., 2021; Tankiz & Uslu, 2022), and the importance of PSTs experiencing the integration of ER in their teaching practices (Oliveira et al., 2023; Schina, Valls-Bautista, et al., 2021). The participants of this study implemented in the practicum lesson plans that integrate ER in the teaching of mathematical content, as shown by the occurrences of epistemic, cognitive, mediational, and ecological categories. The number of occurrences and co-occurrences in Gr6 suggest that the implementation of tasks that promote the manipulation/programming of robots at the same time as the exploration of mathematical content is more advantageous for the development of the didactic knowledge of mathematics needed to integrate ER into the practices of PSTs than the implementation of tasks focused only on the manipulation/programming of robots.

We hope that these results will contribute to the discussion around the role of PSTs in the implementation of curricular tasks that integrate ER in the promotion of mathematical learning (Sapounidis et al., 2023; Schina, Valls-Bautista, et al., 2021). We consider that, in the context of this study, the articulation between mathematics and didactics curricular units with the curricular unit responsible for the practicum contributed to reducing PST difficulties in creating lesson plans that integrate ER in teaching practices (Schmid et al., 2021; Tankiz & Uslu, 2022). This articulation also provided conditions for the PSTs to experience the integration of ER in their practices (Oliveira et al., 2023; Schina, Valls-Bautista, et al., 2021) of mathematics teaching (Sapounidis et al., 2023). The results of this study show the positive influence of the articulation between curricular knowledge, specific didactics, and the practicum. The evidence presented also suggests that the implementation in the practicum of mathematical tasks that promote the manipulation/programming of the robot at the same time as the exploration of mathematical content was beneficial for the development of the participants' didactic knowledge of mathematics. As such, we suggest that future studies in ITT dedicated to the integration of ER in the teaching practices of curricular content include these features, seeking to assess the significance of including this feature in the design of training programs.

CONCLUSIONS

Answering the research question based on the discussion of results, we argue that participation in the proposed training program contributed to the PSTs mobilizing the following knowledge related to the didactic dimension of the DMK conceptual framework:

(i) epistemic–mathematical knowledge needed to teach,

(ii) cognitive–knowledge of students' cognitive aspects,

(iii) interactional–knowledge needed to manage interactions in the classroom during the teaching and learning processes,

(iv) mediational–knowledge of resources and how their integration into the teaching process can influence learning processes, and

(v) ecological–knowledge of the mathematics curriculum, its connections with other curricula and the context in which it is implemented.

We consider that PSTs didn't mobilize knowledge related to students' affective, emotional and behavioral aspects (affective). It is also possible to state that the PSTs mobilized knowledge of learners and their characteristics, knowledge of content and students, and knowledge of content and teaching, which are not part of the DMK conceptual framework but are related to the interactions between its categories.

The PSTs participating in this study mobilized didactic knowledge of mathematics when conducting mathematics teaching processes that integrate ER. The results presented and discussed here offer a contribution to the discussion around the integration of ER in the teaching of mathematical content and regarding the PSTs' actions while integrating ER in their teaching practices, responding to these limitations identified in the literature.

Considering the work carried out, future studies should include PSTs from different contexts, extending the analysis of their practice to a number of groups that would allow the results to be generalized. The lack of experience in integrating technology conditions the PSTs' teaching practices when they do so. As such, future studies should allow PSTs to implement in the practicum multiple mathematical tasks that integrate ER, evaluating the development of PSTs' didactic knowledge of mathematics.

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conceptualization; **RS:** writing–original draft preparation; & **CC, FM, & MCS:** supervision. All authors have agreed with the results and conclusions.

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REFERENCES

Akram, H., Abdelrady, A. H., Al-Adwan, A. S., & Ramzan, M. (2022). Teachers' perceptions of technology integration in teaching-learning practices: A systematic review. *Frontiers in Psychology, 13*, Article 920317. https://doi.org/10.3389/fpsyg.2022.920317

Alqahtani, M. M., Hall, J. A., Leventhal, M., & Argila, A. N. (2022). Programming in mathematics classrooms: Changes in pre-service teachers' intentions to integrate robots in teaching. *Digital Experiences in Mathematics Education, 8*(1), 70-98. https://doi.org/10.1007/s40751-021-00096-6

Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A systematic review of studies on educational robotics. *Journal of Pre-College Engineering Education Research, 9*(2), 19-42. https://doi.org/10.7771/2157-9288.1223

Arocena, I., Huegun-Burgos, A., & Rekalde-Rodriguez, I. (2022). Robotics and education: A systematic review. *TEM Journal, 11*(1) 379-387. https://doi.org/10.18421/TEM111-48

Athanasiou, L., Mikropoulos, T. A., & Mavridis, D. (2019). Robotics interventions for improving educational outcomes–A meta-analysis. *Communications in Computer and Information Science, 993*, 91-102. https://doi.org/10.1007/978-3-030-20954-4_7

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education, 59*(5), 389-407. https://doi.org/10.1177/0022487108324554

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education, 58*(3), 978-988. https://doi.org/10.1016/j.compedu.2011.10.006

Blum, W., Artigue, M., Mariotti, M. A., Sträßer, R., & Van den Heuvel-Panhuizen, M. (2019). European didactic traditions in mathematics: Introduction and overview. In W. Blum, M. Artigue, M. Mariotti, R. Sträßer, & M. Van den Heuvel-Panhuizen (Eds.), *European traditions in didactics of mathematics* (pp. 1-10). Springer. https://doi.org/10.1007/978-3-030-05514-1_1

Breda, A. (2020). Características del análisis didáctico realizado por profesores para justificar la mejora en la enseñanza de las matemáticas [Characteristics of the didactic analysis carried out by teachers to justify the improvement in the teaching of mathematics]. *Bolema: Boletim de Educação Matemática, 34*(66), 69-88. https://doi.org/10.1590/1980-4415v34n66a04

Breda, A., Pino-Fan, L. R., & Font, V. (2017). Meta didactic-mathematical knowledge of teachers: Criteria for the reflection and assessment on teaching practice. *EURASIA Journal of Mathematics, Science and Technology Education, 13*(6), 1893-1918. https://doi.org/10.12973/eurasia.2017.01207a

Breda, A., Pochulu, M., Sánchez, A., & Font, V. (2021). Simulation of teacher interventions in a training course of mathematics teacher educators. *Mathematics, 9*(24), Article 3228. https://doi.org/10.3390/math9243228

Casler-Failing, S. (2021). Learning to teach mathematics with robots: Developing the 'T' in technological pedagogical content knowledge. *Research in Learning Technology, 29*. https://doi.org/10.25304/rlt.v29.2555

Castro, W. F., Pino-Fan, L., & Velásquez-Echavarría, H. (2018). A proposal to enhance preservice teacher's noticing. *EURASIA Journal of Mathematics, Science and Technology Education, 14*(11), em1569. https://doi.org/10.29333/ejmste/92017

Çebi, A., Özdemir, T. B., Reisoğlu, İ., & Çolak, C. (2022). From digital competences to technology integration: Re-formation of pre-service teachers' knowledge and understanding. *International Journal of Educational Research, 113*, Article 101965. https://doi.org/10.1016/j.ijer.2022.101965

Cevikbas, M., König, J., & Rothland, M. (2023). Empirical research on teacher competence in mathematics lesson planning: Recent developments. *ZDM–Mathematics Education, 56*, 101-113. https://doi.org/10.1007/s11858-023-01487-2

Cobb, P., & Gravemeijer, K. (2008). Experimenting to support and understand learning processes. In A. E. Kelly, R. A. Lesh, & J. Y. Baek (Eds.), *Handbook of* *design research methods in education. Innovations in science, technology, engineering and mathematics learning and teaching* (pp. 68-95). Lawrence Erlbaum Associates.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education*. Routledge. https://doi.org/10.4324/9781315456539

Costa, C., Cabrita, I., Martins, F., Oliveira, R., & Lopes, J. B. (2021). Qual o papel dos artefactos digitais no ensino e na aprendizagem de matemática? [What is the role of digital artefacts in teaching and learning mathematics?] In V. Santos, I. Cabrita, T. B. Neto, M. Pinheiro, & J. B. Lopes (Eds.), *Matemática com vida: Diferentes olhares sobre a tecnologia*. UA Editora.

Dong, W., Li, Y., Sun, L., & Liu, Y. (2023). Developing pre-service teachers' computational thinking: A systematic literature review. *International Journal of Technology and Design Education, 34*, 191-227. https://doi.org/10.1007/s10798-023-09811-3

Drijvers, P. (2015). Digital technology in mathematics education: Why it works (or doesn't). In S. J. Cho (Ed.), *Proceedings of the 12th International Congress on Mathematical Education* (pp. 135-151). Springer. https://doi.org/10.1007/978-3-319-17187-6_8

European Commission. (2020). *Digital education action plan 2021-2027–Resetting education and training for the digital age*. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52020DC0624

European Commission. (2022). *Guidelines for teachers and educators on tackling disinformation and promoting digital literacy through education and training*. Publications Office of the European Union.

Font, V., Sánchez, A., & Sala, G. (2022). Prospective teachers' narrative analysis using the didactic-mathematical knowledge and competences model (DMKC). In Y. Chevallard, B. Barquero, M. Bosch, I. Florensa, J. Gascón, P. Nicolás, & N. Ruiz-Munzón (Eds.), *Advances in the anthropological theory of the didactic* (pp. 147-153). Springer. https://doi.org/10.1007/978-3-030-76791-4_13

Gabriele, L., Tavernise, A., & Bertacchini, F. (2012). Active learning in a robotics laboratory with university students. In C. Wankel, & P. Blessinger (Eds.), *Increasing student engagement and retention using immersive interfaces: Virtual worlds, gaming, and simulation: Vol. 6 part C* (pp. 315-339). Emerald Group Publishing Limited. https://doi.org/10.1108/S2044-9968(2012)000006C014

Gavrilas, L., Kotsis, K. T., & Papanikolaou, M.-S. (2024). Assessing teacher readiness for educational robotics integration in primary and preschool education. *Education 3-13*. https://doi.org/10.1080/03004279.2023.2300699

Giacomone, B., Godino, J. D., & Beltrán-Pellicer, P. (2018). Desarrollo de la competencia de análisis de la idoneidad didáctica en futuros profesores de matemáticas [Development of the competency of analysis of didactic suitability in future mathematics teachers]. *Educação e Pesquisa, 44*(0). https://doi.org/10.1590/s1678-4634201844172011

Godino, J. D. (2011). Indicadores de idoneidad didáctica de procesos de enseñanza y aprendizaje de las matemáticas [Indicators of didactic suitability of mathematics teaching and learning processes]. In *Proceedings of the 13th Inter-American Conference on Mathematics Education*.

Godino, J. D., Batanero, C., & Font, V. (2007). The onto-semiotic approach to research in mathematics education. *ZDM, 39*(1-2), 127-135. https://doi.org/10.1007/s11858-006-0004-1

Godino, J. D., Burgos, M., & Gea, M. M. (2022). The onto-semiotic approach in mathematics education. Analyzing objects and meanings in mathematical practice. In Y. Chevallard, B. Barquero, M. Bosch, I. Florensa, J. Gascón, P. Nicolás, & N. Ruiz-Munzón (Eds.), *Advances in the anthropological theory of the didactic* (pp. 51-60). Springer. https://doi.org/10.1007/978-3-030-76791-4_5

Gomes, P., Martins, M., Quaresma, M., Mata-Pereira, J., & da Ponte, J. P. (2022). Task design and enactment: Developing in-service and prospective teachers' didactical knowledge in lesson study. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(7), Article em2131. https://doi.org/10.29333/ejmste/12172

Gomez, F. C., Trespalacios, J., Hsu, Y.-C., & Yang, D. (2022). Exploring teachers' technology itegration self-efficacy through the 2017 ISTE standards. *TechTrends, 66*(2), 159-171. https://doi.org/10.1007/s11528-021-00639-z

Huang, R., & Zbiek, R. M. (2017). Prospective secondary mathematics teacher preparation and technology. In *The mathematics education of prospective secondary teachers around the world* (pp. 17-23). Springer. https://doi.org/10.1007/978-3-319-38965-3_3

Hummes, V., & Seckel, M. J. (2024). Advancing teacher reflective competence: Integrating lesson study and didactic suitability criteria in training. *Frontiers in Education, 9*, Article 1331199. https://doi.org/10.3389/feduc.2024.1331199

Hummes, V., Breda, A., Font, V., & Seckel, M. J. (2023). Improvement of reflection on teaching practice in a training course that integrates the lesson study and criteria of didactical suitability. *Journal of Higher Education Theory and Practice, 23*(14). https://doi.org/10.33423/jhetp.v23i14.6395

Jung, S. E., & Won, E. S. (2018). Systematic review of research trends in robotics education for young children. *Sustainability, 10*(4), Article 905. https://doi.org/10.3390/su10040905

Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers and Education, 91*, 14-31. https://doi.org/10.1016/j.compedu.2015.08.005

Kim, S. A. (2019). Trends in robotics-related curricula of elementary, middle, and high schools in Korea: A review of the 2007, 2011 and 2015 revised curricula. *Universal Journal of Educational Research, 7*(5A), 114-128. https://doi.org/10.13189/ujer.2019.071513

König, J., Bremerich-Vos, A., Buchholtz, C., Fladung, I., & Glutsch, N. (2020). Pre-service teachers' generic and subject-specific lesson-planning skills: On learning adaptive teaching during initial teacher education. *European Journal of Teacher Education, 43*(2), 131-150. https://doi.org/10.1080/02619768.2019.1679115

Krippendorff, K. (2019). *Content analysis: An introduction to its methodology*. SAGE. https://doi.org/10.4135/9781071878781

Kuckartz, U., & Rädiker, S. (2019). Introduction: Analyzing qualitative data with software. In *Analyzing qualitative data with MAXQDA: Text, audio, and video* (pp. 1-11). Springer. https://doi.org/10.1007/978-3-030-15671-8_1

Kucuk, S., & Sisman, B. (2017). Behavioral patterns of elementary students and teachers in one-to-one robotics instruction. *Computers and Education, 111*, 31-43. https://doi.org/10.1016/j.compedu.2017.04.002

Kuhl, P. K., Lim, S.-S., Guerriero, S., & van Damme, D. (2019). *Developing minds in the digital age: Towards a science of learning for 21st century education*. OECD Publishing. https://doi.org/10.1787/562a8659-en

Lai, C., Wang, Q., & Huang, X. (2023). The evolution of the association between teacher technology integration and its influencing factors over time. *Journal of Research on Technology in Education, 55*(4), 727-747. https://doi.org/10.1080/15391523.2022.2030266

Lopes, J. B., Silva, A. A., Cravino, J. P., Santos, C. A., Cunha, A., Pinto, A., Silva, A., Viegas, C., Saraiva, E., & Branco, M. J. (2014). Constructing and using multimodal narratives to research in science education: Contributions based on practical classroom. *Research in Science Education, 44*(3), 415-438. https://doi.org/10.1007/s11165-013-9381-y

Mangina, E., Psyrra, G., Screpanti, L., & Scaradozzi, D. (2023). Robotics in the context of primary and pre-school education: A scoping review. *IEEE Transactions on Learning Technologies, 17*, 342-363. https://doi.org/10.1109/TLT.2023.3266631

Matos, J. F. (2014). *Princípios orientadores para o design de cenários de aprendizagem* [*Guiding principles for gesigning learning scenarios*] Instituto de Educação.

Miller, D. P., & Nourbakhsh, I. (2016). Robotics for Education. In B. Siciliano, & O. Khatib (Eds.), *Springer handbook of robotics* (pp. 2115-2134). Springer. https://doi.org/10.1007/978-3-319-32552-1_79

Ministério da Educação. (2021a). *Aprendizagens essenciais: Matemática* [*Essential learning: Mathematics*]. Ministério da Educação.

Ministério da Educação. (2021b). *Aprendizagens essenciais: Matemática* [*Essential learning: Mathematics*]. Ministério da Educação.

Ministério da Educação. (2021c). *Aprendizagens essenciais: Matemática*. [*Essential learning: Mathematics*]. Ministério da Educação.

Ministério da Educação. (2021d). *Aprendizagens essenciais: Matemática* [*Essential learning: Mathematics*]. Ministério da Educação.

Misirli, A., & Komis, V. (2014). Robotics and programming concepts in early childhood education: A conceptual framework for designing educational scenarios. In C. Karagiannidis, P. Politis, & I. Karasavvidis (Eds.), *Research on e-learning and ICT in education* (pp. 99-118). Springer. https://doi.org/10.1007/978-1-4614-6501-0_8

Moral-Sánchez, S. N., Ruiz Rey, F. J., & Cebrián-de-la-Serna, M. (2023). Analysis of artificial intelligence chatbots and satisfaction for learning in mathematics education. *International Journal of Educational Research and Innovation, 20*, 1-14. https://doi.org/10.46661/ijeri.8196

NCTM. (2014). *Principles to actions: Ensuring mathematical success for all*. National Council of Teachers of Mathematics.

OECD. (2019). *Education policy outlook 2019: Working together to help students achieve their potential*. OECD Publishing. https://doi.org/10.1787/2b8ad56e-en

OECD. (2022). *Mending the education divide: Getting strong teachers to the schools that need them most*. OECD Publishing. https://doi.org/10.1787/92b75874-en

Oliveira, D. S., Garcia, L. T. S., & Gonçalves, L. M. G. (2023). A systematic review on continuing education of teachers for educational robotics. *Journal of Intelligent & Robotic Systems, 107*. https://doi.org/10.1007/s10846-022-01804-z

Parra-Urrea, Y. E., & Pino-Fan, L. R. (2022). Proposal to systematize the reflection and assessment of the teacher's practice on the teaching of functions. *Mathematics, 10*(18), Article 3330. https://doi.org/10.3390/math10183330

Pedro, A., Piedade, J., Matos, J. F., & Pedro, N. (2019). Redesigning initial teacher's education practices with learning scenarios. *International Journal of Information and Learning Technology, 36*(3), 266-283. https://doi.org/10.1108/IJILT-11-2018-0131

Piedade, J., Dorotea, N., Pedro, A., & Matos, J. F. (2020). On teaching programming fundamentals and computational thinking with educational robotics: A didactic experience with pre-service teachers. *Education Sciences, 10*(9), Article 214. https://doi.org/10.3390/educsci10090214

Pino-Fan, L. R., Assis, A., & Castro, W. F. (2015). Towards a methodology for the characterization of teachers' didactic-mathematical knowledge. *EURASIA Journal of Mathematics, Science and Technology Education, 11*(6), 1429-1456. https://doi.org/10.12973/eurasia.2015.1403a

Pino-Fan, L. R., Castro, W. F., & Moll, V. F. (2023). A macro tool to characterize and develop key competencies for the mathematics teacher' practice. *International Journal of Science and Mathematics Education, 21*(5), 1407-1432. https://doi.org/10.1007/s10763-022-10301-6

Pino-Fan, L. R., Godino, J. D., & Font, V. (2018). Assessing key epistemic features of didactic-mathematical knowledge of prospective teachers: The case of the derivative. *Journal of Mathematics Teacher Education, 21*(1), 63-94. https://doi.org/10.1007/s10857-016-9349-8

Plomp, T. (2013). Educational Design Research: A Introduction. In T. Plomp, & N. Nieveen (Eds.), *Educational design research* (pp. 10-51). SLO.

Ramos, J. L. P., Espadeiro, R. G., & Monginho, R. (2022). *Introdução à programação, robótica e ao pensamento computacional na educação pré-escolar e 1.º ciclo do ensino básico. Necessidades de formação de educadores e professores* [*Introduction to programming, robotics and computational thinking in pre-school education and 1st cycle of basic education. Training needs for educators and teachers*]. Centro de Investigação em Educação e Psicologia da Universidade de Évora.

Sala-Sebastià, G., Breda, A., & Farsani, D. (2022). Future early childhood teachers designing problem-solving activities. *Journal on Mathematics Education, 13*(2), 239-256. https://doi.org/10.22342/jme.v13i2.pp239-256

Santos, J. M., & Castro, R. D. R. (2021). Technological pedagogical content knowledge (TPACK) in action: Application of learning in the classroom by pre-service teachers (PST). *Social Sciences & Humanities Open, 3*(1), Article 100110. https://doi.org/10.1016/j.ssaho.2021.100110

Sapounidis, T., & Alimisis, D. (2021). Educational robotics curricula: Current trends and shortcomings. In M. Malvezzi, D. Alimisis, & M. Moro (Eds.), *Education in & with robotics to foster 21st-century skills. EDUROBOTICS 2021. Studies in computational intelligence* (Vol. 982, pp. 127-138). Springer. https://doi.org/10.1007/978-3-030-77022-8_12

Sapounidis, T., Tselegkaridis, S., & Stamovlasis, D. (2023). Educational robotics and STEM in primary education: A review and a meta-analysis. *Journal of Research on Technology in Education, 56*(4), 462-476. https://doi.org/10.1080/15391523.2022.2160394

Scaradozzi, D., Screpanti, L., & Cesaretti, L. (2019). Towards a definition of educational robotics: A classification of tools, experiences and assessments. In L. Daniela (Ed.), *Smart learning with educational robotics* (pp. 63-92). Springer. https://doi.org/10.1007/978-3-030-19913-5_3

Schina, D., Esteve-González, V., & Usart, M. (2021). An overview of teacher training programs in educational robotics: Characteristics, best practices and recommendations. *Education and Information Technologies, 26*, 2831-2852. https://doi.org/10.1007/s10639-020-10377-z

Schina, D., Valls-Bautista, C., Borrull-Riera, A., Usart, M., & Esteve-González, V. (2021). An associational study: Preschool teachers' acceptance and self-efficacy towards educational robotics in a pre-service teacher training program. *International Journal of Educational Technology in Higher Education, 18*, Article 28. https://doi.org/10.1186/s41239-021-00264-z

Schmid, M., Brianza, E., & Petko, D. (2021). Self-reported technological pedagogical content knowledge (TPACK) of pre-service teachers in relation to digital technology use in lesson plans. *Computers in Human Behavior, 115*, Article 106586. https://doi.org/10.1016/j.chb.2020.106586

Seckel, M. J., & Font, V. (2020). Competencia reflexiva en formadores del profesorado de matemática [Reflective competence in mathematics teacher trainers]. *Magis, Revista Internacional de Investigación en Educación, 12*(25), 127-144. https://doi.org/10.11144/Javeriana.m12-25.crfp

Seckel, M. J., Breda, A., Farsani, D., & Parra, J. (2022). Reflections of future kindergarten teachers on the design of a mathematical instruction process didactic sequences with the use of robots. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(10), Article em2163. https://doi.org/10.29333/ejmste/12442

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14. https://doi.org/10.2307/1175860

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Silva, R., Costa, C., & Martins, F. (2024). Pre-service teachers' perceptions towards integrating educational robotics in the primary school. *EURASIA Journal of Mathematics, Science and Technology Education, 20*(4), Article em2419. https://doi.org/10.29333/ejmste/14356

Sophokleous, A., Christodoulou, P., Doitsidis, L., & Chatzichristofis, S. A. (2021). Computer vision meets educational robotics. *Electronics, 10*(6), Article 730. https://doi.org/10.3390/electronics10060730

Souza, C. de, Júnior, A. S., & Barbosa, F. (2019). A interseção da robótica educacional e a matemática na formação inicial de professores: Reflexões acerca das conexões matemáticas [The intersection of educational robotics and mathematics in initial teacher training: Reflections on mathematical connections]. In N. Amado, A. P. Canavarro, S. Carreira, R. S. Ferreira, & I. Vale (Eds.), *Livro de atas do EIEM 2019, encontro de investigação em educação matemática* (pp. 387-400). SPIEM.

Stein, M. K., Engle, R. A., Smith, M. S., & Hughes, E. K. (2008). Orchestrating productive mathematical discussions: Five practices for helping teachers move beyond show and tell. *Mathematical Thinking and Learning, 10*(4), 313-340. https://doi.org/10.1080/10986060802229675

Tabach, M., & Trgalová, J. (2019). The knowledge and skills that mathematics teachers need for ICT integration: The issue of standards. In G. Aldon, & J. Trgalová (Eds.), *Technology in mathematics teaching: Selected papers of the 13th ICTMT Conference* (pp. 183-203). Springer. https://doi.org/10.1007/978-3-030-19741-4_8

Taimalu, M., & Luik, P. (2019). The impact of beliefs and knowledge on the integration of technology among teacher educators: A path analysis. *Teaching and Teacher Education, 79*, 101-110. https://doi.org/10.1016/j.tate.2018.12.012

Tankiz, E., & Uslu, N. A. (2022). Preparing pre-service teachers for computational thinking skills and its teaching: A convergent mixed-method study. *Technology, Knowledge and Learning, 28*, 1515-1537. https://doi.org/10.1007/s10758-022-09593-y

Toh, L. P. E., Causo, A., Tzuo, P. W., Chen, I. M., & Yeo, S. H. (2016). A review on the use of robots in education and young children. *Educational Technology and Society, 19*(2), 148-163.

Tondeur, J., Van Braak, J., Siddiq, F., & Scherer, R. (2016). Time for a new approach to prepare future teachers for educational technology use: Its meaning and measurement. *Computers & Education, 94*, 134-150. https://doi.org/10.1016/j.compedu.2015.11.009

Tzagkaraki, E., Papadakis, S., & Kalogiannakis, M. (2021). Exploring the use of educational robotics in primary school and its possible place in the curricula. In M. Malvezzi, D. Alimisis, & M. Moro (Eds.), *Education in & with robotics to foster 21st-century skills* (Vol. 982, pp. 216-229). Springer. https://doi.org/10.1007/978-3-030-77022-8_19

Uslu, N. A., Yavuz, G. Ö., & Koçak Usluel, Y. (2022). A systematic review study on educational robotics and robots. *Interactive Learning Environments, 31*(9), 5874-5898. https://doi.org/10.1080/10494820.2021.2023890

Wilson, M. L. (2023). The impact of technology integration courses on preservice teacher attitudes and beliefs: A meta-analysis of teacher education research from 2007-2017. *Journal of Research on Technology in Education, 55*(2), 252-280. https://doi.org/10.1080/15391523.2021.1950085

You, H. S., Chacko, S. M., & Kapila, V. (2021). Examining the effectiveness of a professional development program: Integration of educational robotics into science and mathematics curricula. *Journal of Science Education and Technology, 30*, 567-581. https://doi.org/10.1007/s10956-021-09903-6

Zha, S., Jin, Y., Wheeler, R., & Bosarge, E. (2022). A mixed-method cluster analysis of physical computing and robotics integration in middle-grade math lesson plans. *Computers & Education, 190*, Article 104623. https://doi.org/10.1016/j.compedu.2022.104623

Zhong, B., & Xia, L. (2020). A systematic review on exploring the potential of educational robotics in mathematics education. *International Journal of Science and Mathematics Education, 18*, 79-101. https://doi.org/10.1007/s10763-018-09939-y

APPENDIX A

Table A1. Co-occurrence of DSC components in Gr3

Codes	Ep2	Ep3	Ep4	Ep5	Ep6	C1	C2	C3	C6	C7	I1	I2	I5	I6	I7	I8	I9	M1	M2	M3	M5	M7	M8	A1	A2	A3	A5	Ec1	Ec2	Ec4
Ep2																														
Ep3	1																													
Ep4	0	1																												
Ep5	0	1	1																											
Ep6	2	2	1	1																										
C1	0	1	1	1	1																									
C2	2	2	1	1	2	2																								
C3	0	0	0	0	0	1	0																							
C6	2	1	0	0	5	0	1	0																						
C7	2	1	0	0	2	2	3	1	2																					
I1	0	0	0	0	0	0	0	0	0	6																				
I2	2	0	0	0	2	0	0	0	2	3	2																			
I5	1	0	0	0	0	0	1	0	0	6	8	2																		
I6	1	0	0	0	0	0	1	0	0	8	2	5	6																	
I7	0	0	0	0	0	0	0	0	0	1	0	1	1	1																
I8	1	1	0	0	3	0	1	0	3	4	1	0	0	1	0															
I9	1	0	0	0	2	0	0	0	2	9	3	7	1	4	1	8														
M1	1	0	0	0	2	0	1	0	2	4	3	3	1	2	0	2	5													
M2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1												
M3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
M5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3										
M7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
M8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1								
A1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
A3	0	0	0	0	0	0	0	0	0	1	0	4	0	1	2	0	0	0	0	0	0	0	0	0						
A5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1				
Ec1	3	1	1	1	5	2	2	1	3	10	4	8	2	5	1	3	14	10	1	0	0	0	0	0	0	1	0			
Ec2	2	1	1	1	1	1	2	0	1	7	4	5	1	5	1	3	11	8	0	0	0	0	0	0	0	3	0	14		
Ec4	4	1	0	0	5	0	2	0	4	12	17	11	5	4	1	6	12	13	1	0	1	0	0	1	0	5	0	19	26	

APPENDIX B

Table B1. Co-occurrence of DSC components in Gr6

Codes	Ep2	Ep3	Ep4	Ep5	Ep6	C1	C2	C3	C5	C6	C7	I1	I2	I3	I4	I5	I6	I7	I8	I9	M1	M2	M3	M5	M6	M7	M8	A1	A3	A4	Ec1	Ec2	Ec4
Ep2																																	
Ep3	0																																
Ep4	2	0																															
Ep5	3	1	18																														
Ep6	13	1	18	22																													
C1	3	1	2	3	3																												
C2	3	1	2	3	4	4																											
C3	3	1	3	4	5	5	4																										
C5	8	3	15	19	31	2	1	4																									
C6	11	1	18	18	38	1	2	3	31																								
C7	8	2	4	7	18	2	2	2	16	16																							
I1	6	0	3	2	6	3	2	2	1	5	3																						
I2	13	0	0	2	11	1	1	2	12	10	12	3																					
I3	1	0	0	1	2	0	0	0	1	2	2	0	1																				
I4	1	0	0	0	2	0	0	0	1	1	3	0	3	0																			
I5	11	0	0	1	4	0	0	0	5	3	5	4	12	0	2																		
I6	12	0	1	4	17	0	1	1	14	15	14	0	14	1	2	7																	
I7	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1																
I8	2	0	13	13	16	1	1	3	19	16	8	3	6	0	0	1	2	0															
I9	12	1	2	4	20	0	1	2	27	20	24	0	18	1	3	11	23	0	8														
M1	7	1	16	17	22	2	3	5	20	21	5	3	5	1	1	2	6	0	16	8													
M2	7	1	16	17	22	2	3	5	20	21	5	3	5	1	1	2	6	0	16	8	27												
M3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
M5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1										
M6	0	11	0	1	2	0	0	0	1	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0									
M7	0	3	0	1	2	0	0	0	2	0	2	0	0	0	0	0	2	0	0	1	0	0	0	0	6								
M8	0	6	0	1	2	0	0	0	2	0	2	0	0	0	0	0	2	0	0	1	0	0	0	0	9	6							
A1	5	2	14	15	17	5	3	7	18	16	4	3	3	0	0	3	3	0	16	4	18	18	0	0	0	0	0						
A3	0	0	1	2	2	0	0	7	2	1	1	0	6	0	0	3	3	2	2	2	1	1	0	0	1	1	1	0					
A4	1	0	0	1	2	0	0	0	1	2	2	0	1	1	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0				
Ec1	20	2	15	20	37	5	5	7	31	33	21	10	22	2	2	9	22	0	19	31	25	25	0	0	1	1	1	23	4	2			
Ec2	22	2	18	21	37	5	5	7	29	35	20	10	22	2	1	12	21	0	19	28	26	26	0	0	1	1	1	22	4	2	59		
Ec4	16	2	16	19	29	5	4	8	26	28	10	10	16	1	1	12	13	0	20	25	26	26	0	0	1	1	1	25	6	1	44	55	